Preservation of Sweet Sorghum Biomass*

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Summary

Sweet sorghum stalks [42% sugar, dry basis (d.b.)] and bagasse (10% sugar, d.b.) from a cane mill were stored to preserve sugar. Bagasse and stalks were stored outdoors in sealed containers (anaerobic conditions). Treatments included using carbon dioxide or sulfur dioxide atmospheres or surface spraying with propionic acid or aqueous ammonia. Stalks were also stored outdoors under aerobic conditions. Treatments included drying the stalks or spraying with propionic acid. After 200 days, propionic acid (anaerobic) and SO_2-treated stalks had 34% and 19% of the original sugar remaining, respectively. No other samples had more than 3% of the original sugar remaining.

INTRODUCTION

The sweet, succulent stalks of sweet sorghum [*Sorghum bicolor* (Moench)] contain about 12% sugar, mainly as sucrose [1]. After harvest, the sugar can deteriorate rapidly, depending on climatic conditions. If sweet sorghum is to be used as raw material for alcohol or chemicals, this deterioration must be prevented [2–8]. More importantly, if sweet sorghum is to reach its potential as a biomass crop, the storage time after harvesting must be at least 6 months, preferably longer. A plant processing only sweet sorghum must be economically acceptable, and a short processing season increases capital costs due to the need for oversized equipment [9]. The biomass potential of sweet sorghum thus depends to a large extent on the development of long-term storage methods.

Until about 1965, many American farmers raised small plots of sweet sorghum, crushed the mature stalks in a cane mill, and made sorghum syrup from the juice. Storage of the stalks was of little interest since they were crushed within a few days of harvesting. In the most extensive storage study of this period, Coleman and Stokes stored stripped stalks of sweet sorghum for 16 days under wet and dry conditions [10]. However, they were mainly inter-

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ested in the effects of storage on sucrose inversion to glucose and fructose, juice expression using a cane mill, and syrup making. Their data are of limited value in predicting effects of long-term storage on sugar content. Other studies from this period were also of limited duration (1 to 2 days of storage) [11–14].

Most of the recent work on sweet sorghum has involved juice storage and fermentation [15,16]. Daeschel, Mundt, and McCarty found that freshly squeezed sweet sorghum juice spoiled within 5 to 12 h at ambient temperatures [17]. The fresh juice contained 10^8 microorganisms per mL, mainly *Leuconostoc mesenteroides* and gram-negative rods, with some lactobacilli, yeasts, and nonfecal coliform bacteria. Day and Sarkar found that Wray sweet sorghum juice contained fermentation inhibitors that increased with plant maturity [18]. Fink was able to increase the sugar content of sweet sorghum juices by enzymatic saccharification of starch, while protecting the sugar solution from microbial attack [7].

Very little work has been done on whole-stalk storage. Eiland, Clayton, and Bryan found that forage-chopped Wray lost about half of its sugar content in 8 days, with about 14% of the total sugar lost in the first day [19]. Total sugars were constant in whole-stalk Wray stored for 8 days.

Other agricultural crops have been stored successfully for long periods of time [20–22]. Grains can be safely stored in silos for at least 1 yr by lowering moisture content below 15% [23]. Moist grain that is undergoing extended ambient air drying can be protected from microbial deterioration by treatment with ammonia or sulfur dioxide [24,25]. Anaerobic storage of grains, including nitrogen or carbon dioxide atmospheres, can be effective [26]. Wet hay (35% moisture) can be protected by 1 to 2% propionic acid [27]. Sugar cane bagasse (50% moisture and 3% sugar) can be protected from molds for 18 months by using 2% propionic acid [28].

Maintenance of quality in the whole sweet sorghum stalk presents a real challenge in preservation. The stalk has a high moisture content (70%) and contains highly fermentable sugars. The waxy coating that protects the stalk from drought also makes it difficult to dry. There are many microorganisms present that the preservative must control, including molds, bacteria, and yeasts. Finally, any physical or chemical treatment used must be inexpensive and not interfere with future processing.

This paper presents results for aerobic storage of whole sweet sorghum stalks, and for anaerobic storage of both stalk sections and bagasse from stalks crushed in a cane mill. Propionic acid, ammonia, sulfur dioxide, and a carbon dioxide atmosphere were used as preservatives.

EXPERIMENTAL

Sweet Sorghum

Two sweet sorghum varieties, Wray and Keller, were grown at three locations in central Illinois. At harvest, the seed heads were removed and the leaves

were stripped from the stalks. The stripped stalks of sweet sorghum at the three locations had an average solids content of 29%, of which 42% was sugar.

Anaerobic Bagasse Storage

On October 23, 1981, bagasse was obtained from a small, local sorghum producer. The fresh bagasse (from a vertical three-roll mill) had a solids content of 42%, of which 10.1% was sugar. The variety of the sweet sorghum used was not known. Twenty pounds of bagasse was put into each of 6 large clay tiles (18 in. diam, 36 in. height). There were two replications of three treatments (see Table I). After treatment, the tile tops were sealed with two layers of 5-mil plastic. The tiles had one-way vent tubes to relieve excess pressure. The plastic covers were also able to move up or down about 1 ft, which allowed the container volume to respond to pressure changes. The tile bottoms had been sealed with concrete and epoxy paint to prevent leakage. After 200 days of outdoor storage, the tile contents were weighed and samples were taken for solids and sugar analyses.

Aerobic Stalk Storage

On October 6, 1981, about 835 lb of Wray sweet sorghum was harvested from one location. After sampling, the remaining material (804 lb) was divided into four (201 lb) bundles, which were treated as shown in Table II. The sweet sorghum had a solids content of 29%, of which 41% was sugar. Three bundles were immediately stored (outdoors) on pallets. Two of these bundles were laid horizontally and the third was rested vertically against a fence. One

TABLE I

Anaerobic Bagasse Storage Treatments

Treatment[a]	Level
None	...
Carbon dioxide	100% atmosphere
Propionic acid	2.5% wet basis[b]

[a] Duplicate experiments.
[b] 0.5 lb of acid sprayed on.

TABLE II

Aerobic Stalk Storage Treatments

Stacking position	Treatment[a]	Solids content
Vertical	None	29%
Horizontal[b]	None	29%
Horizontal	1% Propionic acid[c]	29%
Horizontal	Dried	41%

[a] Single experiments.
[b] Control.
[c] Wet basis, 2 lb of acid sprayed on.

of the horizontal bundles was left untreated as a control. The vertical bundle was also left untreated. The second horizontal bundle was treated by surface spraying with propionic acid and encased in plastic for 24 h to permit penetration by the propionic acid. The amount of propionic acid used was 1% of the weight (wet basis) of the stalks treated. The fourth bundle was dried for 18 h at 150°F in a Proctor-Schwartz pilot-plant belt drier. The solids content increased to 41% (final weight of 142 lb). The dried bundle was then laid horizontally, and all three horizontal bundles were covered within thin canvas dropcloths. After 200 days the bundles were weighed, and whole-stalk samples were taken for solids and sugar analyses.

Anaerobic Stalk Storage

On October 8, 1981, 560 lb of stalks was harvested from the two other plot locations and cut into 2-ft sections. After sampling, the stalk sections were divided into 50-lb bundles, which were placed into 10 clay tiles (outdoors). The stalk sections had a solids content of 28%, of which 43% was sugar. There were two replicates for each of five treatments (see Table III). The tiles were sealed as described previously, either immediately (for the control and SO_2 treatments) or after treatment (for the CO_2, aqueous NH_3, and propionic acid treatments). After 200 days in storage, the tile contents were weighed and samples were taken for solids and sugar analyses.

Analyses

Solids content was measured by drying the samples at 221°F (105°C) until constant weight was achieved. Samples for sugar analysis were dried at 150°F for 18 h. Stalk samples had to be split lengthwise before drying. The samples were then ground in an Abbe mill (model No. 30625) using a 3/32-in. screen (dry ice was normally added along with the high sugar content samples to prevent stalling). Sugars were extracted from the ground sample using a 75% water–25% ethanol mixture (at room temperature, for 2 h on a shaker). Sucrose, glucose, and fructose concentrations were determined by high-pressure liquid

TABLE III
Anaerobic Stalk Storage Treatments

Treatment[a]	Level, % w.b.
None	...
Propionic acid	2.0[b]
Aqueous ammonia	1.2[c]
Carbon dioxide	(100% atmosphere)
Sulfur dioxide	2.0[d]

[a] Duplicate experiments.
[b] 1.0 lb of acid sprayed on.
[c] 0.6 lb of NH_3 sprayed on (2.0 lb of 30% NH_3).
[d] 1.0 lb of SO_2 applied as gas.

chromatography using a Bio Rad (Richmond, CA) HPX-42 size-exclusion column with water as the mobile phase.

RESULTS AND DISCUSSION

Bagasse Storage

The untreated bagasse was not expected to store well because of its high moisture content (58%) and the fact that the sugar (10.1%, d.b.) was more susceptible to microbial attack. The propionic acid and CO_2 treatments were expected to have some effect on the mold and bacterial growth. However, the results in Table IV show that none of the treatments were effective in preserving sugar content, with no detectable sugars remaining after 200 days in storage. There was no apparent difference in the preservation of solids either, with about 60% being the average of original solids remaining. Bagasse from the control and treated tiles had a similar appearance and odor, typical of ensiled materials. Unpublished reports indicate that SO_2 treatment may preserve sugar content in forage-chopped sweet sorghum. If this is true, then SO_2 may be useful for bagasse storage. However, there is already a large quantity of sugarcane bagasse available, and the sweet sorghum bagasse may be worth more as animal feed than as a sugar, chemical, or fiber source. It may also be easier to recover sugar from the bagasse at processing time by washing rather than to preserve it on the bagasse.

Aerobic Stalk Storage

Table V gives results for the 200-day aerobic storage of whole stalks. No detectable sugars were found in any of the samples. The untreated sample stalks were very moldy, and when split had a sour, fermented odor. The stalks broke easily when handled. The dried-treatment stalks were also very moldy and broke easily; although there was no sugar in the stalks, the percentage of initial solids remaining was high, about 84%. It is unfortunate that it is difficult to dry the stalks without first splitting them. The stalks treated with propionic acid and the vertically stored stalks had very little mold on them. The

TABLE IV
Bagasse Storage

	Solids			Sugar	
Treatment	Initial (lb)	Final (lb)	% of Initial remaining	Initial (lb)	Final (lb)
None	8.3	5.0	60	0.85	0
CO_2	8.3	4.6	55	0.85	0
Propionic acid	8.3	5.4	65	0.85	0

[a] All results on dry basis.

TABLE V

Aerobic Stalk Storage

Treatment and position	Solids			Sugar	
	Initial (lb)[a]	Final (lb)	% of Initial remaining	Initial (lb)	Final (lb)
None[b] horizontal	58	29	50	24	0
None vertical	58	42	72	24	0
Dried horizontal	58	49	84	24	0
Propionic acid horizontal	58	42	72	24	0

[a] All results on dry basis.
[b] Control.

stalks did not break with handling, but when split they had the same sour odor as the control stalks. In both cases about 72% of the original solids remained.

Although none of the treatments prevented the loss of sugar, it must be realized that this was a severe storage test. Ambient temperatures ranged from −10 to 80°F. Aerobic storage of stalks probably is not feasible except for short periods or when ambient temperatures are low. Stalks might be split lengthwise and dried, but this method would be expensive and would lead to other problems, such as juice loss and microbial contamination.

Anaerobic Stalk Storage

Results (Table VI) show that the CO_2 and aqueous ammonia treatments were no better than the control in preserving sugar content. However, the propionic acid treatment showed promise, with about 34% of the original sugar remaining after 200 days. The SO_2 treatment was less effective, with about 19% of the original sugars being preserved. When the tiles were opened, the control, ammonia, and CO_2-treated stalks were in poor condition. The SO_2 and propionic acid-treated stalks had much less mold and no sour odor.

TABLE VI

Aerobic Stalk Storage

Treatment	Solids			Sugar		
	Initial (lb)[a]	Final (lb)	% of Initial remaining	Initial (lb)	Final (lb)	% of Initial remaining
None	14.2	8.6	61	6.1	0.08	1.3
Propionic acid	14.2	10.8	76	6.1	2.1	34[b]
Aqueous ammonia	14.2	9.4	66	6.1	0.18	3.0
CO_2	14.2	9.0	63	6.1	0.12	2.0
SO_2	14.2	10.8	76	6.1	1.15	18.9[b]

[a] All results on dry basis.
[b] Significantly different than control at 95% level of confidence.

The SO_2-treated stalks had been bleached, whereas the propionic acid-treated stalks looked very much like fresh stalks.

None of the treatments preserved a major portion of the original sugars. However, the SO_2 and propionic acid treatments deserve more study. Possibly deterioration occurred mainly during the warm, spring weather of the last 50 days of storage. If this was the case, a second treatment at the end of cold winter weather may be effective. The effect of treatment level on sugar preservation also needs to be investigated.

CONCLUSIONS

Most treatments failed to preserve sweet sorghum biomass for the long period of time needed for presumed economic feasibility (at least 200 days). No detectable sugars remained in bagasse stored anaerobically or in whole stalks stored aerobically. Two treatments of sectioned stalks stored anaerobically showed the most promise: propionic acid-treated stalks had 34% of the original sugar remaining after storage, whereas SO_2-treated stalks had 19% of the original sugar remaining. Further work is necessary to optimize treatment levels and to determine when sugar loss occurs.

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